

# **Modeling Improved Parameterizations of Shallow Water Ocean Physics into Simulation Models for AUVs**

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## **LONG-TERM GOALS**

To improve AUV mission effectiveness, and the quality of AUV-based scientific research, by quantifying important ambient process contributors to platform noise, drag, and instabilities.

## **OBJECTIVES**

- (1) To quantify AUV response to water column dynamics through spectral and temporal analysis, with particular attention to (a) swell and surface waves, (2) solitons and internal waves, and (3) currents with transverse components.
- (2) To provide predictive dynamic models for important processes and platform interactions. Also, To provide detailed suggestions for improvement in vehicle design for platform quietness, stability, improved endurance, controller design/optimization, and interactive intelligent response to ambient processes in the littoral ocean.

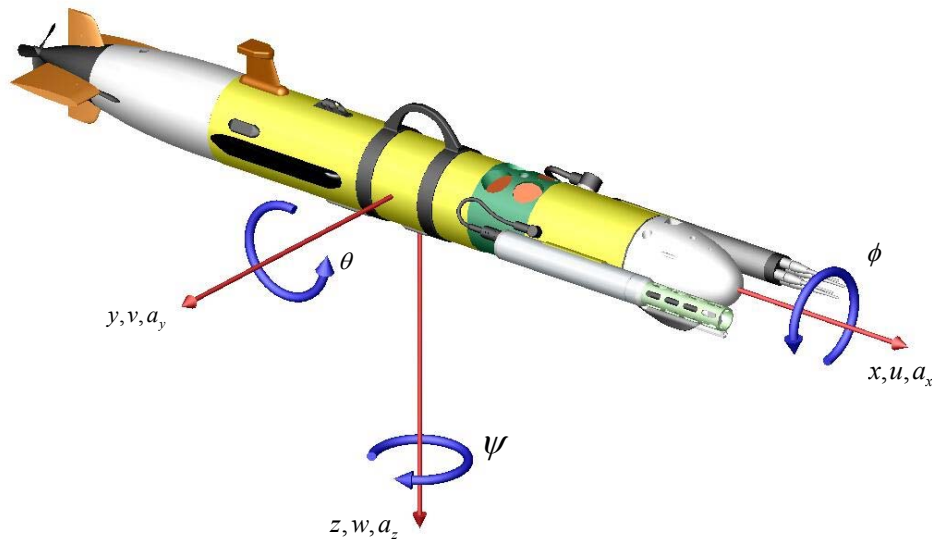
## **APPROACH**

### *(1) Spectral and temporal analysis of field data*

Synoptic scientific and vehicle response data are required for evaluation of environmental effects, and their elimination/interpretation in AUV-derived field studies. Specific test cases of interest include during a variety of surface wave, swell, internal wave, and soliton conditions. Local experiments are conducted in Narragansett and Buzzards Bays. Additional experiments with opportunities for larger swells and breaking solitons are conducted during the LOCO experiment in Monterey Bay. For the observed Thin Layers, earlier work has shown that unique blends of ambient turbulence, finescale shear, stratification, and possible mixing processes such as internal waves are required. Maintaining

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an optimum AUV trajectory through these features is required for scientific and tactical applications, and the limitations of the platform must be quantified.



**Figure 1. CAD rendering of the TREMUS-2 AUV with three orthogonal axes of translation (red lines) and principle Euler rotations about these axes. The RGL turbulence package (port) and the Seabird CTD (starboard) are cantilevered off the bow. The upward-looking RDI ADCP transducers are imbedded in the body. The downward looking ADCP and WetLabs Fluorometer/OBS are not visible.**

## *(2) AUV Modeling, Improvement*

Nahon's (1996) six degree of freedom model is being modified for the extended turbulence measuring REMUS, complete with bow cantilevered sensors (Fig. 1). Using work of Prestero (2001), we are upgrading the external force and moment characterizations for our model, as well as upgrading the controller module. More recent work in improving REMUS hydrodynamics modeling at NPS to be considered also includes Fodrea (2002). Goodman et al (2006) discuss the use of a suite of AUV motion sensors to optimize ambient coastal turbulence measurements.

## **WORK COMPLETED**

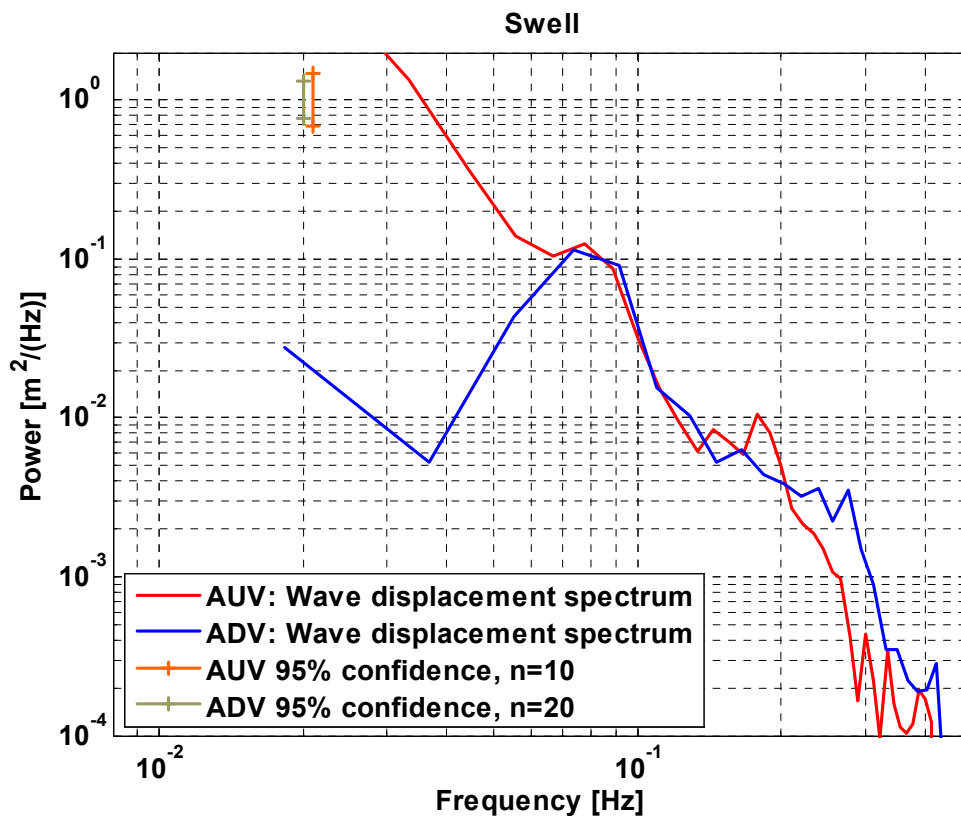
- (1) Overall, our ULI M.S. graduate student, Christopher Luebke, has made excellent progress towards a better understanding of AUV/ environment interactions, and the completion of his degree requirements, anticipated for Spring 2007.
- (2) Technically, a six degree of freedom vehicle dynamics model, Nahon (1996), was modified for the turbulence measuring AUV, also adding more realistic swell and internal wave characterizations.

(3) Technically, scientific and vehicle dynamics data have been obtained over a wide variety of coastal conditions in Monterey Bay, Narragansett Bay, and Buzzards Bay, including interesting surface waves, swell, internal waves, and soliton conditions.

## RESULTS

### *(1) AUV Response to Swell*

Calculated wave displacement spectra (Figure 2), using a model which utilizes in situ pressure and vertical acceleration data, are consistent with nearby moored ADV-measured spectra. The broad peak in the ADV pressure (blue) spectrum is indicative of swell measured by the upward facing transducer. Wave displacement spectrum derived from T-REMUS data (red) shows a similar response at the swell's frequency, i.e., approximately .08 Hz ( $T \sim 13$  seconds).

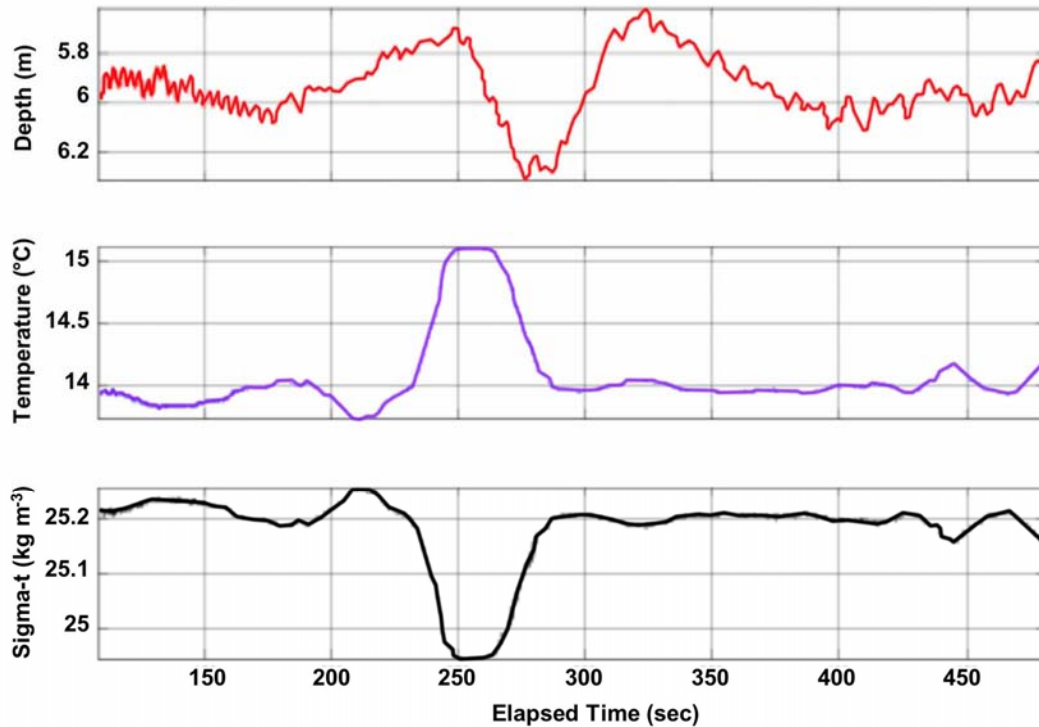


**Figure 2. Autospectra of AUV measured swell/surface wave displacement, and moored ADV-measured wave displacement, 10 and 20 degrees of freedom were used for AUV and ADV, respectively.**

### *(2) AUV Response to Solitons/internal waves*

In the 2005 Monterey Bay experiment, in the most dramatic soliton-related event, the AUV density change encountered during level flight, of  $0.2 \sigma_t$ , occurred on August 15, 2005 at 1326 PST. This discontinuity drove T-REMUS off course by 0.6 m vertically. Figure 3 illustrates T-REMUS's encounter with lower density water. T-REMUS, trying to maintain a depth of approximately 6 m, normally oscillates slowly (a greater than 20-second period) about the depth goal. While at depth, the

amplitude of oscillations resulting from the PID depth controller is generally less than 0.15 m. However, a dramatic feature occurred from 1333 and 30 seconds to 1334 hours (centered about 275 seconds in Figure 3) during the August 15, 2005 fourth run. The AUV derived corresponding temperature and sigma-t time series showed perturbations of approximately 1.0 oC, and 0.3 kg m-3, respectively.



**Figure 3. AUV derived depth (top), temperature (center) and density (lower,  $\sigma_t$ ) records from T-REMUS, August 15, 2005; during a period of soliton activity.**

A simple force balance may be written summing the buoyant and hydrodynamic forces acting upon the AUV body due to the passage of solitons or internal waves. From this, AUV displacement resulting from vertical components of the soliton/internal waves buoyant and hydrodynamic forces can be estimated. This result will be compared with the in situ AUV obtained data in Fig. 3.

## IMPACT/APPLICATIONS

- (1) Enable emerging AUVs to operate optimally in more challenging environments such as in evolving solitons, and large swells.
- (2) Provide more realistic modeling capabilities for AUVs in very challenging environments for military as well as scientific missions.

## **TRANSITIONS**

The research conducted here will impact Future Naval Capabilities associated with:

- Autonomous Operations - Enable automated surveillance and reconnaissance in all environmental conditions.
- Littoral ASW - Characterize the battle-space to provide for a common tactical/environmental picture.
- Organic MCM – provide VSW reconnaissance.

## **RELATED PROJECTS**

- AUV Turbulence Measurements in the LOCO Field Experiments
- ONR Vector Sensors Departmental Research Initiative

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